

MISSION AND DESIGN OF AN ORBITING RADIO ASTRONOMY EXPLORER

by

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Earth-based radio astronomical observations have added considerably to our knowledge of the planetary system, the galaxy and the universe in general. However, these observations are confined to a "window" in the earth's atmosphere through which radio waves may propagate. This window, which extends approximately from 10 Mc to 15,000 Mc, is limited at the high frequency end by molecular absorption in the lower atmosphere and at the low frequency end by the earth's ionosphere and terrestrial radio interference.

Radio astronomers have recognized that it should be possible to extend observations several decades down in frequency by placing suitable instrumentation aboard rockets and satellites which attain altitudes above the major portion of the terrestrial ionosphere. Pioneering work⁽¹⁾ in this area was carried out by the radio astronomy groups of Harvard University, the University of Michigan, the Canadian DRTE, Cambridge University in Great Britain and the USSR. The observations made to date have been obtained with essentially nondirective antennas (short dipoles). Because of the technological problems associated with deployment of long antennas, some investigators have suggested utilizing the earth's ionosphere to obtain angular resolution or directivity by focusing⁽²⁾.

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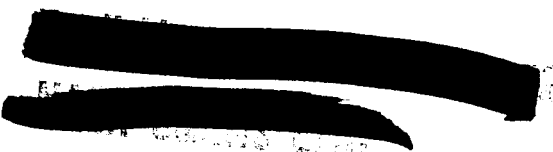
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This article outlines some of the scientific missions of space radio astronomy as well as a system studied extensively at the NASA Goddard Space Flight Center for making these observations. This system, the Radio Astronomy Explorer (RAE), is designed to measure the intensity of radio signals from celestial sources as a function of frequency, position and time with a directive antenna. ~~(At this writing the Radio Astronomy Explorer program has not been funded.)~~

The low frequency limit to which observations can be carried is determined by the ambient ionospheric electron density which in turn governs the frequency (electron plasma frequency) at which the index of refraction of the medium approaches zero⁽³⁾. In practice it is difficult to approach this observing limit because of the behavior of the antenna in a magnetoionic medium. There exists sufficient experimental evidence⁽⁴⁾ to conclude that at an altitude of 6000 km, it will be possible to make measurements down to frequencies as low as 300 kc.

GALACTIC STUDY

Synchrotron regions and ionized hydrogen (HII) significantly affect the measured cosmic noise from the galaxy. Synchrotron radiation⁽⁵⁾ results from the motion of relativistic electrons in a magnetic field. Under a number of



simplifying assumptions, it may be shown that the radio emission from the synchrotron process is a function of the interstellar magnetic field, the observing frequency and the energy spectrum of the relativistic electrons. Because of an inverse frequency dependence, synchrotron emission predominates over other processes (such as thermal emission) at low frequencies. A study of the spatial and spectral distribution of synchrotron emission should provide some very significant additional information about the interstellar magnetic fields and the galactic relativistic electron spectrum. If these relativistic electrons are produced in the formation of cosmic rays, radio measurements at low frequencies may shed some light on the problem of cosmic ray formation in our galaxy.

Ionized hydrogen⁽⁶⁾ (HII) shows a definite concentration toward the plane or disk of our galaxy but is also distributed in an inhomogeneous fashion throughout the galactic corona. This ionized hydrogen, which is the main source of (thermal) emission at high frequencies, shows up in absorption at low frequencies. After passing through a region of ionized hydrogen of electron density n , kinetic temperature T_e , and thickness L , a signal of intensity I_0 will be reduced to $I = I_0 e^{-\tau}$, where the optical depth τ is proportional to

$$\frac{1}{T_e^{3/2} f^2} \int_0^L n^2 ds$$

This free-free absorption will cause the observed cosmic noise spectrum to turn over and subsequently decrease with decreasing frequency. On the basis of galactic models, measurements of absorption, and thus of optical depth, will enable astronomers to estimate electron density and/or kinetic temperatures in an HII region.

At a sufficiently low frequency an HII cloud will become opaque, producing a "screen" which may be utilized, for example, to separate the contributions of emission originating in the infra-solar distance from that beyond the HII cloud.

A further modification in the observed cosmic noise spectrum may result from a break in the cosmic ray electron spectrum. This break may be expected to occur when the energy loss by the synchrotron process (for the higher energy electrons) equals approximately the energy loss by ionization (for softer electrons). A break in the spectrum will provide information about the cosmic ray electron spectrum and interstellar magnetic field.

SOLAR ASTRONOMY

The sun emits a wide and complex variety of radio bursts throughout the observed spectrum⁽⁷⁾. It is anticipated that even below the ionospheric cut-off, solar bursts will be sufficiently intense to be easily detected against the cosmic

noise background. Certain types of sporadic radio bursts presumably are generated when solar corpuscular streams and solar cosmic radiation pass through the corona and generate plasma waves. A part of this energy is transferred into electromagnetic waves of the appropriate frequency and, thus, gives rise to the observed emission.

The extension of results obtained from ground based observations suggests that the observation of solar bursts over the proposed RAE frequency range would provide important information about the outer regions of the solar corona, i.e. to distances around 20-30 solar radii. Based upon models of the solar corona, values of electron density and temperature in this range of the corona can be determined. Observation of the intensity of the burst as well will help in studying the interaction between particle streams and coronal plasma.

PLANETARY ASTRONOMY

After nearly a decade of investigation, the mechanism of Jupiter's sporadic emission is still not clear. Observational tests of the theoretical models have been hampered seriously due to the effects of the earth's ionosphere⁽⁸⁾. For example, although the decameter emission has been observed as high as 40 Mc, ionospheric absorption makes the determination of the low frequency spectrum and cut-off impossible from the

ground. Measurements from above the ionosphere will enable astronomers to determine the spectrum of Jupiter radio emission at low frequencies. Such data are of considerable importance in testing or developing a theory of the emission mechanism and its subsequent interpretation in terms of the structure of the planet's magnetosphere.

The apparent similarity in the magnetospheres of the earth and Jupiter make the occurrence of terrestrial noise bursts quite likely. The RAE concept will allow not only detection of terrestrial noise storms, but also the measurement of their distribution at low frequencies.

THE SYSTEM

As stated earlier, the few low frequency spaceborne measurements which have been obtained, clearly indicate the need for directive antennas. Directivity will provide a means of "mapping" the spatial distribution of cosmic noise, and it will facilitate observations of sporadic bursts from a particular source without possible confusion from other sporadic sources. If space radio astronomy is to progress much further, a means of obtaining directivity is essential. Although it is conceivable that some type of ionospheric focusing will provide directivity, it is our feeling that since the technological problems of large space antennas can be solved, the development of highly directive antennas is

possible. The RAE concept represents the results of a study which has provided the design of a first generation radio astronomy experiment with a directive antenna system.

THE ANTENNA

In selecting an antenna it was necessary to find a system with sufficient directivity to facilitate the accomplishment of the scientific missions and at the same time to decide if the system could be deployed from the spacecraft. If it could be deployed, would it operate satisfactorily when exposed to the forces encountered in the space environment?

As illustrated in the Figure ___, the proposed spacecraft is essentially an orbiting antenna system. In the normal operating mode, the system is composed of four 750-~~1000~~-foot elements connected to form a pair of V antennas apex to apex. Clearly a single long linear antenna is mechanically simple, but it has several drawbacks including the conical main beam shape, a bidirectional pattern, and excessively high side lobes. A considerable improvement in electrical characteristics is gained by combining two linear elements into a V antenna. This array can be made reasonably broadbanded, has good impedance characteristics, and provides at least an order of magnitude beamwidth improvement over a dipole. However,

a standing wave V antenna has an objectionable bidirectional pattern. By inserting proper resistive terminations in the legs, the antenna behaves as a traveling wave antenna. In this way the back lobe can be suppressed 20 db.

A desirable but not imperative feature of the radio astronomy experiment is gravity gradient attitude stabilization. It is desirable principally because (a) it greatly facilitates the reduction of data and (b) it provides a means of observing simultaneously and separately the terrestrial and celestial noise. This allows differential techniques to be utilized for analysis.

The Figure ____ is a power pattern obtained from scaled model studies for a terminated V antenna several wavelengths long. Although the antenna array will provide gain over a dipole throughout its operating range from 300 kc to 7 Mc, it was specifically designed to produce significant directivity from approximately 1 to 7 Mc. Note that the four elements of the array can be combined to provide several types of antennae with beam characteristics suitable for particular observations. Theory and the experimental data for the various antenna combinations will be published elsewhere.

The elements which comprise the antenna are of the motor-driven DeHavilland type already successfully used on several

satellites and demonstrated for 850 foot lengths in the laboratory. This device is a pre-stressed metal strip which forms into a tubular structure upon deployment.

The behavior of long tubular elements in the space environment poses serious problems because of the gravity gradient forces, solar pressure, and thermal bending. For example, a typical element of Beryllium-Copper would have a tip deflection of 500 feet for a 1000 foot long element.

The engineering study carried out at Goddard Space Flight Center and the Applied Physics Laboratory of John Hopkins University has thoroughly demonstrated that by proper choice of element characteristics, however, a satellite with a mechanically stable antenna system consisting of elements at least 750 feet long can be placed into a 6000 km circular orbit. The Figure ____ illustrates the effects of gravity gradient forces and thermal bending on the initial array shape. Note that the initial root angle can be selected to provide a desired final V angle in order to compensate for the bending. Model antenna studies have demonstrated that the expected boom bending does not seriously affect the required electrical characteristics of the array.

INSTRUMENTATION

The Figure ____ is a block diagram of the radio astronomy instrumentation. For long term, unattended operation, use of

the Ryle-Vonberg closed loop radiometer is the most desirable technique for radio noise measurements since it has the advantage of accuracy and stability even in the event of variations in receiver gain and bandwidth. The completely solid state engineering model which has been developed incorporates 10-frequency operation, automatic range switching to attain 60 db of dynamic range, and a zero-i.f. system.

To relate the power absorbed by the antenna to that available at its terminals, the antenna impedance must be measured so that the transfer function can be computed. Since the antenna will be in a plasma environment which may vary, and since the antenna shape may vary, it is necessary to make these impedance measurements periodically. An impedance probe which accurately measures both resistive and reactive components of impedance has already been developed and flight tested.

With the exception of a part of the spacecraft power supply, the remaining instrumentation shown in the block diagram is similar to equipment which has already been flight proven. DC to DC converters in the spacecraft power supply system are a possible source of considerable noise. Since this noise falls within the observing frequency band of the satellite, it cannot be tolerated. A converter incorporating slow

switching and integrated shielding has been demonstrated to successfully eliminate this interference.

In the final analysis the orbit selected was governed by both the realization of the desired observing frequency range, the orbital precession rate, and a tolerable gravity gradient boom deflection. A thrust-augmented Thor-Delta rocket with a Nots 100B apogee kick motor is capable of placing the spacecraft into a 6000 km, circular orbit with a 50° inclination. The Figure ____ illustrates the launch and injection sequence.

CONCLUSION

The results of the study have clearly demonstrated the feasibility of the Radio Astronomy Explorer. The RAE would not only provide significant scientific information but would also provide the basic unit for future, more sophisticated, experiments to obtain high resolution surveys by means of aperture synthesis. A system of this type would provide the scientific community with an observatory from which a variety of experiments could be performed.

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